Documenting Fine-Sediment Import and Export for Two Contrasting Mesotidal Flats

Charles A. Nittrouer
School of Oceanography
University of Washington
Seattle, WA 98195-7940
phone: (206) 543-5099 fax: (206) 543-6073 email: nittroue@ocean.washington.edu

Award Numbers: N00014-07-1-0930, N00014-08-1-0789

LONG-TERM GOALS

The general goal of this project is to examine the seabed, quantitatively document the fluxes of fine sediment (over different time scales), and thereby validate localized measurements and numerical models of sediment transport.

OBJECTIVES

The specific objectives are to:

a) document changes in bed elevation (deposition, erosion) on time scales intrinsic to the driving forces; e.g., tidal cyclicities, wind-driven currents and local waves, river discharge, and interannual variability;
b) measure net accumulation rates over decades at many sites to calculate fine-sediment budgets for both Willapa and Skagit tidal systems;
c) examine sedimentation at sufficient locations to characterize spatial variability of grain size and its vertical stratification.

APPROACH

The tidal-flat sedimentation in Willapa mud flats and Skagit sand flats will be contrasted, with a focus on understanding the import of mud to the Willapa flats and the export of mud from the Skagit flats. This involves development of sediment budgets to document quantitatively the fate of muddy sediment, and also includes investigation about the variability for sedimentation of several time scales.

Because UW is located near the Willapa and Skagit tidal flats, we are helping to provide logistical support to colleagues traveling long distances to work in these areas. We have also helped obtain the substantial number of permissions needed for the research, and have acted as the primary contact for the federal, state and county regulatory agencies.

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE **2009**		2. REPORT TYPE			3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Documenting Fine-Sediment Import and Export for Two Contrasting Mesotidal Flats**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,School of Oceanography,Seattle,WA,98195-7940**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

WORK COMPLETED

During 2008-2009, three extended surveys were completed in Willapa Bay for detailed observations and sampling: Sep 2008, one week (spring tide); March 2009, two weeks (spring and neap tides); July 2009, two weeks (spring and neap tides). In addition, regular trips were taken to Willapa Bay (approximately once per month) for time-series sampling and for testing newly constructed equipment. As part of the project, a mobile barge was designed and built for spatial sampling in shallow water, and also for semi-diurnal time-series observations at fixed locations (using its jack-up capability. Additionally, a coring device was constructed that allowed collection of cores (40 cm long) from boat or barge, with little impact on the muddy tidal flat. The cores are easily examined by x-radiography and subsampled for radiochemical and grain-size analyses.

A number of factors necessitate that the sampling strategy for the Skagit Bay tidal-flat system be different than in Willapa Bay. A major distinction is the direct input from the Skagit River of much new sediment (3-4 million tons/year), which is supplied by a bimodal hydrograph. During the late spring and early summer, gradual snow melt in high elevations provides much freshwater and fluvial sediment. During the late autumn and early winter, rainfall events (at times coupled with rapid snow melt in low elevations) provide episodic floods of the river with much suspended sediment. Small boats were used to sample the tidal flat, and sampling occurred during these two periods of high discharge: Jun-Jul 2008, Nov 2008-Jan 2009, and Jun-Jul 2009. In addition, cruises on ships were undertaken to the subtidal areas of the dispersal system (e.g., Saratoga Passage, Deception Pass) in order to document Skagit sediment that bypassed the tidal flats. These cruises occurred during the periods between high discharge: Aug 2008 (R/V Barnes), Feb 2009 (R/V Centennial), Aug 2009 (R/V Centennial) and on two academic cruises in Apr 2008 and Apr 2009 (both on the R/V Barnes).

RESULTS

Willapa Bay

Observations have documented tidal asymmetry of sediment transport on the Willapa flats. For example, during the latter stages of ebbing tide in March, much mud was moved into and down channels as high-concentration flows. The concentrations of suspended sediment were much reduced in July. During March, x-radiographs in channel thalwegs reveal distinct physical stratification with laminae 1-3 cm thick, which were likely formed during the ebb flows.

On seasonal time scales, evidence of variability was observed in several ways. The floors of secondary tidal channels (e.g., tributaries to Bear Channel) showed a dramatic change between winter conditions (March, 2009) and summer conditions (July, 2009). The muddy channel bottoms with physical stratification (laminae 1-3 cm thick) gave way to a shell-hash pavement (Fig. 1) in summer. The presence of a shell-hash layer ~20 cm below the winter channel bed suggests that seasonal input and removal of sediment (tens of centimeters thick) is a regular occurrence.

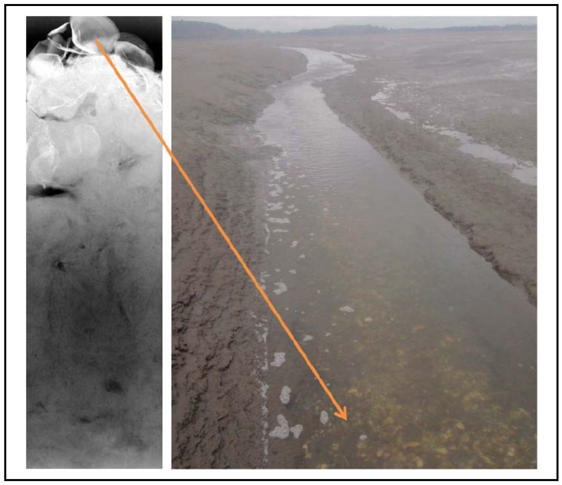

Fig. 1 – C channel of Willapa Bay during July 2009, with shell hash at base. This can be seen in top of x-radiograph shown to left, and is similar to the buried shell-hash layer observed during winter.

^{7}Be (half life 53 days) is an indicator of recent sediment input from a terrestrial source. ^{7}Be was commonly found in the surficial seabed after winter flooding (i.e., samples collected in March), and indicated import of sediment likely from local streams. ^{234}Th (half life 24 days) on particles is an indicator of scavenging from ocean water (with dissolved ^{234}Th) and/or sediment that had been in the ocean outside Willapa Bay soon before collection of seabed samples (<3 mos). ^{234}Th was found in almost all surficial sediment samples collected during winter 2009.

Numerous cores (~40) have been collected for measurement of sediment accumulation rates by ^{210}Pb geochronology (half life 22.3 y). Eventually these will be used to create a budget for sediment accumulating on the tidal flat in southern Willapa Bay. The cores have been collected with clear recognition of their location with respect to local morphology (e.g., channel, bank, flat), due to expected differences in sedimentary processes.

Several signatures have been recognized so far. These include cores that seem to have broken records of accumulation – steady-state sediment accumulation for 20-40 years, following an erosional break (Fig. 2). Accumulation rates are typically 3-7 mm/y, although rates <2 mm/y are found on some portions of the flats and some sites in channels (e.g., cut banks) are erosional. Accumulation rates in other areas of the flats seem to be very rapid. Nearly uniform excess ^{210}Pb is observed to extend deep into the seabed (>40 cm), which makes accumulation rates difficult to calculate because present cores are too short. But the thickness of excess ^{210}Pb likely indicates high rates of sediment accumulation (>2 cm/y) in these places. Vibracores have been collected and will provide longer ^{210}Pb profiles.

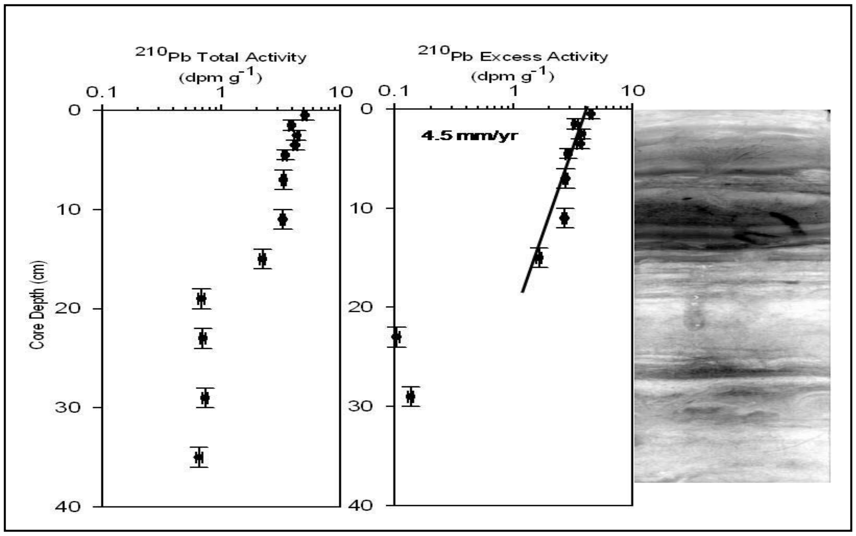

Fig. 2 – Core from Willapa central channel. Indicates accumulation at a rate of 4.5 mm/y for past ~40y. Break in ^{210}Pb profile at ~20 cm depth may indicate this accumulation followed a period of erosion. Dominance of physical stratification in x-radiograph precludes significant impact of bioturbation.

All cores collected for measurement of sediment accumulation rates have been examined by x-radiography, and typical stratification is demonstrated by Fig. 2. Physical stratification dominates the channels, banks and most of the flat surface. However, some parts of the flats show impact from bioturbation, and are mottled or homogenous. The sediment grain size is predominantly silt and clay, but the distinct physical laminae indicate that the grain size of deposited sediment changes through time. Despite the dominance of silt and clay, samples from the north-central portion of the flat contain some sand. Future grain-size analyses will quantify sediment texture at all core sites.

Skagit Bay

The surface of the Skagit tidal flats commonly has ripples associated with tidal currents and/or surface waves. These features demonstrate the dynamic and sandy character of the flats. Following high discharge events, ephemeral mud deposits were found several centimeters thick and containing ^{7}Be. In addition, graded sand layers (i.e., upward fining) were found ~10 cm thick, suggesting input from suspension. The ephemeral mud and graded sand deposits were located along the flanks of the Skagit North Fork.

^{7}Be is typically associated with silt and clay particles, because they are more chemically reactive than sand particles. The distribution of ^{7}Be following discharge events shows that most silt and clay bypasses the sandy portion of the Skagit flats, and is especially common on the outer fringe of the flats. Surface samples collected on the winter cruise following high discharge events also revealed ^{7}Be in northern Saratoga Passage and west of Deception Pass.

Despite the ephemeral muds, no thick or extensive mud deposits have been observed on the tidal flats at the river mouth. Muds are transported to the subtidal region, and accumulate there. The only subtidal portion of Skagit Bay is a narrow channel along the west side of the bay, near Whidbey Island, but extensive deposits of modern mud are not found there either. Much mud is transported into Saratoga Passage, and is accumulating there at rates ~1 cm/y in the northern portion of the passage (Fig. 3). Excess ^{210}Pb is also found in muddy patches west of Deception Pass, suggesting that some Skagit fine-grained sediment is leaving in that direction.

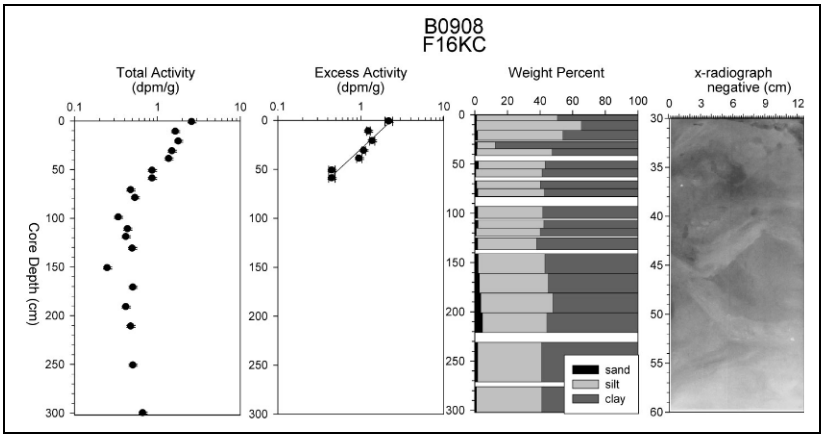

Fig. 3 – Kasten core from northern Saratoga Passage. Total ^{210}Pb activity decreases to supported levels at ~100 cm depth in core. Excess activity indicates an accumulation rate of ~1 cm/y. The seabed is ~60% clay and 40% silt, and benthos are able to bioturbate intensely and destroy physical sedimentary structure (as seen in X-radiograph negative).

The flats are primarily composed of sand, with fine and very fine sands dominating (2-4 phi, 64-256 µm; Fig. 4). The sediment buried in the flat is dominated by cross bedding, with very little evidence of bioturbation. Mud within the seabed is largely restricted to thin layers (few centimeters thick), which is surprising because the Skagit River discharges millions of tons of mud each year. Most of the sediment in Saratoga Passage is mud (Fig. 3) and this area is the likely destination for much of the missing sediment, possibly along with the region outside Deception Pass.

IMPACT/APPLICATIONS

The research completed in this project leads to an improved understanding of the processes that control the geometry of sedimentary deposits over multiple time scales and in diverse oceanographic settings. The tidal-flat studies will provide an understanding of rate and type of sediment (mud, sand) emplaced on tidal flats, which are critical for understanding the surface morphology (e.g., channel configuration) and internal character (e.g., sediment stratification that affects strength).

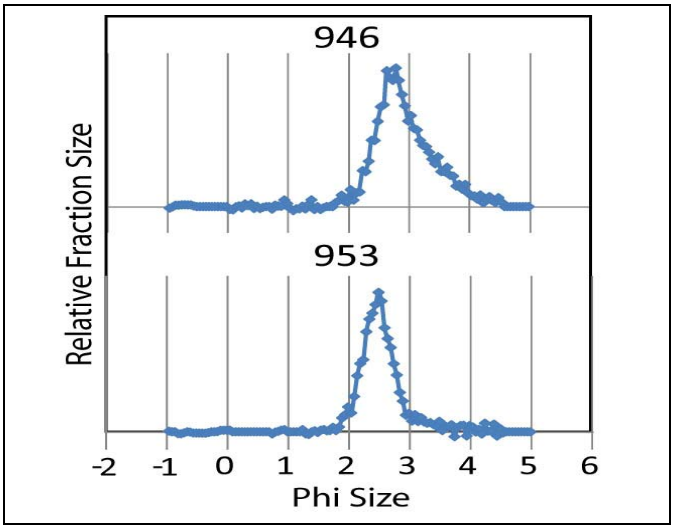

Fig. 4 – Grain-size distributions for two typical surface samples from Skagit tidal flats. Lower sample (953) is well sorted fine sand. Upper sample (946) has a tail extending into very fine sand and silt.

TRANSITIONS

Other investigators in the Tidal Flats DRI are transferring the results from this effort into their projects. Those studying the seabed incorporate radiochemical and textural data to document the processes (e.g., physical reworking, bioturbation) impacting seabed characteristics. Researchers analyzing boundary-layer processes also utilize these data to determine instrumentation sites. Accumulation rates, sediment budgets, and grain-size data are key components to input parameters for numerical models.

RELATED PROJECTS

Related projects include studies of: the seabed by R. Wheatcroft and P. Wiberg; boundary-layer processes by A. Ogston, R. Geyer, P. Traykovski, and D. Ralston; suspended-sediment dynamics by P. Hill, B. Law and T. Milligan; seabed thermal processes by J. Thomson and C. Chickadel.

PUBLICATIONS

Boldt, K., Nittrouer, C.,and Ogston, A. (2009) Linking sediment transport processes to laminated seabed deposits in a fine-grained tidal flat: Willapa Bay, WA. Coastal and Estuarine Research Federation, 20th Biennial Conference, Portland OR.

Nittrouer, C., Lee, K., and Ogston, A. (2009) Export of mud from the Skagit River tidal flats. Coastal and Estuarine Research Federation, 20th Biennial Conference, Portland OR.

Ogston, A., Lee, K., Boldt, K., Hale, R., Nittrouer, C. (2009) Tidal Asymmetry of sediment-transport dynamics on intertidal flats: two contrasting examples. Coastal and Estuarine Research Federation, 20th Biennial Conference, Portland OR.